Final Report -- UVI Online Search Tool (UVI-OST)

Title of Grant:	A Climatological Database of Auroral Images for Solar Cycle 23: An Online Synoptic Search and Metadata Visualization Tool
Type of Report:	Final Performance Report
Principal Investigator:	G. A. Germany
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Summary of research objectives and plan

The primary goal of the funded work was to provide an online search and visualization tool of auroral and geophysical metadata covering the ascending phase of the last solar cycle (23). Prior to this program, there were no tools available for searches of auroral features or for visualization of derived parameters such as boundaries, energy input, or presence of given auroral morphologies. The lack of such tools meant that the vast majority of current research using auroral images is event-driven, where the only search criteria is the time of the event. The logistical difficulties of organizing synoptic studies spanning extended times, or of finding particular auroral morphologies regardless of the time of their occurrence, is one of the primary impediments for performing non-event-driven auroral studies.

Most important results during project

1. Developed an online search interface to instrument metadata and geophysical data. Online search tool first made available for public access in January 2002 and updated over the course of the project.

2. Developed automated, unsupervised 'miner' algorithms to extract image content information from UVI data set. This, in turn, opened new and unexpected avenues for scientific investigation.

3. Developed image content-based parameters and added to the online search engine.

4. Developed an automated data delivery service.

5. Developed prototype 'temporal mining' algorithms to identify substorm morphologies and track their subsequent evolution.

6. Explored advanced topics, including automated evaluation of image quality and enhanced segmentation methods.

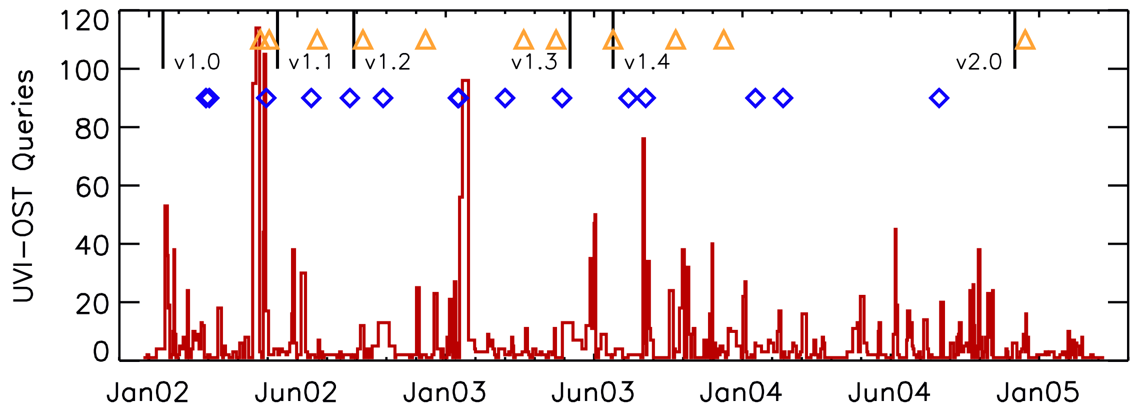

Figure 1. User OST queries.

General summary of performance

Impact. Since going online in January 2002, the UVI Online Search Tool (OST) has been steadily used by the scientific community. Figure 1 summarizes usage to date. The figure shows daily OST queries along with prominent community abstract/notice-of-intent deadlines (blue diamonds), meeting/proposal deadlines (gold triangles), and OST upgrades (vertical markers at top). Through March 23, 2005, there were a total of 6,738 queries from 324 unique IP addresses representing over 100 different institutions in 19 countries. Table 1 lists the host countries of users that have made OST queries.

Table 1. Source of user queries

Country	Unique IP Addresses	Country	Unique IP Addresses
Australia	2	Italy	1
Austria	4	Japan	31
Belgium	1	Norway	12
Canada	20	Poland	2
Finland	1	Russia	24
France	7	South Korea	13
Great Britain	21	Sweden	6
Iceland	1	United States	171
India	2	Zambia	1
Ireland	1		

User Interface. In the first year of the project an initial search tool was created based on existing UVI metadata. This tool served as the foundation of the work done in the remainder of the project.

The online search tool (UVI-OST; http://csds.uah.edu/uvi-ost/) allows queries of instrument parameters, field of view location, spacecraft location, and geophysical indices. Query results are display as onscreen sortable tables, downloadable text files, or as graphical summaries.

UVI-OST was announced for public access on January 22, 2002 and the response was very positive, with over 300 visits to the site in the first two weeks and more than forty subscriptions to our email list. System logs indicate a dedicated core of users worldwide performing focused searches rather than randomly trying out features. It was clear that the site was meeting the needs of the scientific community, as expected.

The initial search tool had a shortcoming in that there was no way of easily evaluating the quality of the requested data. This could be quickly evaluated by visual inspection of UVI images, but OST didn't originally supply that information. Therefore, we decided to provide links from the user query result page to online images maintained by the UVI science team. The online images constitute the official UVI data product and are available to all users. Adding this link allowed the user to judge the quality of the UVI data. However, the interface was awkward since the user had to follow a web link for every record in the query result.

Therefore we decided to added thumbnail images directly to the query result page. This required preprocessing every record to generate the thumbnail image, storing the images on the web server, and then adding the filename of each thumbnail to the OST database. Since the preprocessing algorithm structure had to be in place for the image miner development, this didn't represent a great departure from our original plans. This enhancement is a great success. The user can quickly judge the quality of the selected data simply by scrolling in the web browser.

During the thumbnail development, we noticed that many database records corresponded to the UVI background filter position. This wasn't a problem originally, since we didn't report filter information. (We store one record every 10 minutes, but UVI creates a record every 37 seconds. It was felt that reporting filter information would be misleading since the filter at the time sampled by the database was somewhat random.) The use of thumbnails, however, meant we had to be more careful in our selection of records for the OST database. A new database was thus constructed that included background records only if they were the only available filter during the ten minute period.

As part of our initial image miner development we paid particular attention to the location of the UVI field of view. It soon became clear that the ability to ask if a ground station was in the UVI field of view would be valuable. This was confirmed by OST users who we contacted and a list of desirable (~120) ground stations was compiled with the help of users. We developed an algorithm that determined where each ground station was relative to the UVI field of view and then stored a flag for each station in the OST database. The current OST interface allows users to restrict their search by this additional criterion.

The original metadata collection was expanded to include non-image metadata. Non-image metadata includes information such as spacecraft coordinates and location of the UVI field of view. This information has been included in the current UVI-OST. In addition, this category has been expanded to included topics originally believed only available from image analysis. These topics include percent of field of view on Earth, percent of oval in field of view, and image quality. Additional parameters include OMNI solar wind data and activity indices. All of these parameters are intended to allow the user to refine his query requests to only the image types of most use.

The original project design considered OST as a search tool only. The output would be a list of UVI time stamps that matched the search criteria. The user was then expected to contact a UVI team member directly to receive the data. This design choice reflected initial concerns about our capabilities and UVI data policy at the time. During the course of the project it became clear that we could easily overcome any technicalities in delivering data to the user. After consulting with the UVI Principal Investigator, it was decided to create a data server whereby the output from the user search could be used to create a custom data set of UVI images that could then be downloaded by the user. A basic software toolkit and viewer was also created.

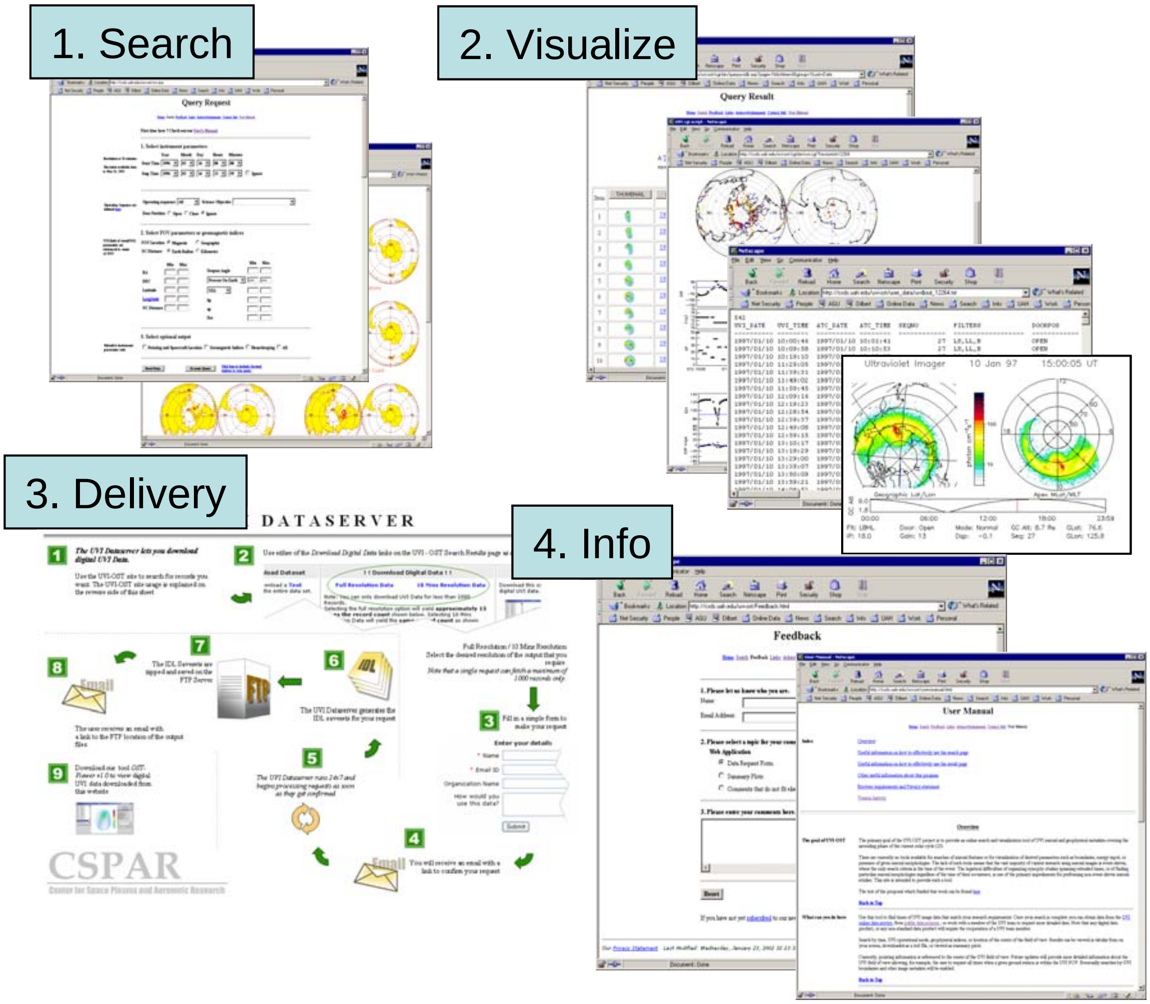

Figure 2. Overview of UVI OST user interface.

Segmentation algorithm. A key part of the image miner algorithm development was the k-means algorithm developed by Dr. C.-C. Hung at Southern Polytechnic State University under a subcontract to this research program. This algorithm identifies which pixels are within the auroral oval and effectively ignores non-auroral pixels. Once this determination is made, it is possible to use ancillary information to find auroral boundaries, areas, and integrated intensities. Much of this information is stored as a function of local time. In addition, it is possible to estimate how much of the oval is seen within the UVI field of view. This information is also stored in the OST database.

The k-means algorithm, like other algorithms explored for auroral image location, doesn't perform well in the presence of dayglow. Therefore, we decided to build a statistical model of the airglow seen by UVI. We used our miner technology to examine summer-time UVI images for five years. Based on this we derived a simple analytical form that accurately modeled the airglow seen in UVI images. Using this model, we remove airglow then apply the k-means algorithm to the UVI data.

Because of the effort to model the airglow, and the complexity of the image miners, we didn't try to meet our original deadline of completing the miner development in Fall 2002. For that reason, and the loss of key personnel, a no-cost extension was requested in the final year of funding to complete the image miner development.

Synoptic studies. One of the profound realizations from this project was the knowledge that the collected search database represented a potentially useful source for synoptic studies of auroral morphology and high-latitude energy input into Earth's upper atmosphere. We presented a series of papers featuring multi-year analysis of auroral activity and exploring the utility image-based activity metrics. These papers, in turn, lead to several fruitful scientific collaborations. This was particularly gratifying in that this was the entire rationale for this project, namely that the need for a tool to enable multi-year synoptic studies.

Emery et al., Image Comparisons with the Auroral Electron and Ion Hemispheric Power after Intersatellite Adjustments and Geophysical Variations, Space Weather Week, 2005.

Germany, G.A., J.F. Spann, C. Deverapalli, and C. Hung, The utility of auroral image-based activity metrics, Eos. Trans. AGU, 85(47), Fall Meet. Suppl., Abstract SA51B-0247, 2004.

Germany, G.A., C.-C. Hung, R.A. Doe, D. Lummerzheim, and G.K. Parks, Multi-year analysis of FUV auroral images, *Eos Trans. AGU, 84*(46), Fall Meet. Suppl., Abstract SM51B-0516, 2003.

Hung, C. C., and G. Germany, K-means and Iterative Selection Algorithms in Image Segmentation, in *IEEE Southeast Conference, Session 1: Software Development*, Jamaica, West Indies, 2003.

Germany et al., Multi-year analysis of FUV auroral images, SM51B-0516, Fall AGU 2003.

Doe et al., Impact of Global Averaging on UVI-based Bz North Conductance Estimates, SM51B-0517, Fall AGU 2003.

Germany, G. A., C. Hung, D. Chua, Y. Tung, J.F. Spann, and G.K. Parks, Extended Synoptic Analysis Using a Database of Auroral Images, *Eos Trans. AGU, 83*(47), Fall Meet. Suppl., Abstract SM12A-0486, 2002.

Unfinished business. Despite the overwhelming success of this program, there are some topics that merit further investigation. First of all, we began this program with a stringent limitation on the segmentation algorithm. Because we were concerned about available computer resources we decided to avoid complex, potentially computer-intensive segmentation algorithms. The k-means algorithm we developed was selected precisely because it is not computer intensive. However, we now realize that the concern about limited computer resources was unfounded. In light of this realization, it would be useful to explore other segmentation algorithms that may be more robust for our applications.

We also encountered surprising difficulties attempting to develop automated image quality measures. No single algorithm was applicable across our full data set. We explored some more advanced automated image quality metrics, but were unable to fully develop these techniques.

Finally, the most intriguing development from this work was the possibility of developing a database of temporal evolution of auroral morphology. The most obvious example of this evolution is the substorm expansion and recovery cycle. However, there are also distinct temporal morphologies associated with solar wind pressure pulses and theta auroras. Our earlier ability to automatically identify substorm bulges based on extracted boundaries is especially promising and could be the first phase of a more detailed development of temporal evolution tools. The ability to automatically identify and track substorm development opens the ability of new classes of synoptic investigations. Such investigations are not currently realistic endeavors, but this would change with the addition of temporal evolution to our existing tool.